

Jet Studies in STAR via 2+1 Correlations

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Abstract.

This paper reports analysis on jet-medium interactions and di-jet surface emission bias at RHIC, based on a new multi-hadron correlation technique called 2+1 where back-to-back high p_T hadron triggers work as proxy of di-jets. In contrast with traditional correlations with single triggers, the associated hadron distributions and spectra at both trigger sides show no evident modification from d+Au to central Au+Au collisions. This observation stands for both cases when triggers pairs are symmetric($p_T > 5\text{GeV}/c$ vs. $p_T > 4\text{GeV}/c$) or asymmetric($E_T > 10\text{GeV}/c$ vs. $p_T > 4\text{GeV}/c$).

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INTRODUCTION

Di-hadron correlation measurements in heavy ion collisions using a single high- p_T trigger have observed broader distributions of associated hadrons on the away-side azimuthal ($\Delta\phi \sim \pi$) [1, 2] in heavy ion collisions relative to $p+p$ and $d+Au$, and a long-range $\Delta\eta$ plateau called *ridge* at near-side ($\Delta\phi \sim 0$) [3]. However, they don't identify the away side jet which may endure more jet-medium interaction. On the other hand, two high- p_T hadron correlations exhibit jet-like peaks in both near-/away-sides [4, 5] with little shape modification from d+Au to central Au+Au, but a strong suppression on the away-side amplitude. The data may be interpreted in two scenarios: in-medium energy loss followed by in-vacuum fragmentation, and finite probability to escape the medium without interactions. The analysis in this paper uses a new 3-particle (2 + 1) correlation technique, which measures the correlation of low- p_T particle with a pair of back-to-back high- p_T trigger pair as proxy of di-jets. The asymmetry between the two triggers p_T are varied as an attempt to control the path length each parton travels in the medium, thus the difference between their final energy.

ANALYSIS AND RESULT

This paper is based on data collected by the STAR (Solenoidal Tracker at RHIC) experiment [6] in the years 2003-2004 and 2007-2008 of collisions events center-of-mass per nucleon pair energy of 200 GeV, of both d+Au and Au+Au. The Au+Au data are divided into multiple centrality bins based on the charged track multiplicity at mid-rapidity ($|\eta| < 0.5$). The number of participating nucleons (N_{part}) and the number of binary collisions (N_{coll}) for each centrality bin used in the analysis are calculated via Monte-Carlo Glauber model. The high- p_T trigger pairs are required to be back-

to-back $|\phi_{trig1} - \phi_{trig2} - \pi| < 0.2$ to work as proxy of dijets. The associated hadrons $1.5 \text{ GeV}/c < p_T^{assoc} < p_T^{trig1}$) is selected to coincide with the range where the broad away-side and the near-side ridge are reported. The correlation functions are defined as

$$\frac{d^2N}{d\Delta\eta d\Delta\phi} = \frac{1}{N_{trig}\epsilon_{pair}} \left(\frac{d^2N_{raw}}{d\Delta\eta d\Delta\phi} - a_{zyam} \frac{d^2N_{Bg}}{d\Delta\eta d\Delta\phi} \right)$$

N_{trig} is the number of trigger pairs, and $d^2N_{raw}/d\Delta\eta d\Delta\phi$ is the associated hadron distributions corrected by ϵ_{pair} for single-track efficiency and pair acceptance effects. The background $\frac{d^2N_{Bg}}{d\Delta\eta d\Delta\phi}$ is estimated from mixing-event technique after being modulated by the flow [7]. The background due to randomly associated triggers as di-jets [8] is also considered from trigger-trigger correlation in a similar way. The overall background level a_{zyam} is then decided with the Zero-Yield at Minimum (ZYAM) method [9]. The p_T spectra for associated hadrons is measured within 0.5 radians in $\Delta\phi$ and 0.5 in $\Delta\eta$ of the respective trigger direction, with background removed. The systematic uncertainties from all sources and items above are evaluated. Their sums are highest in central Au+Au events (<20%) and much lower in d+Au and peripheral Au+Au, and strongly correlate between same-/away-sides and mostly cancel out for such comparisons.

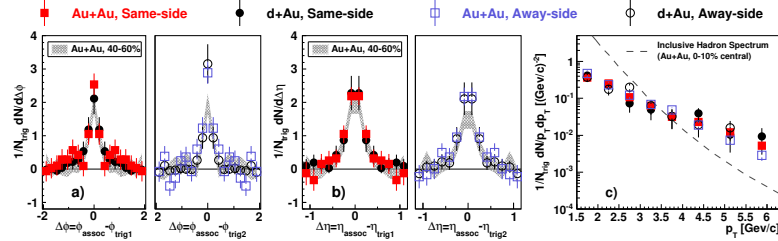


FIGURE 1. Projections of 2+1 correlation on $\Delta\phi$ (a) and $\Delta\eta$ (b) for 200 GeV Au+Au and d+Au data [10]: $5 < p_T^{trig1} < 10 \text{ GeV}/c$, $4 \text{ GeV}/c < p_T^{trig2} < p_T^{trig1}$, $1.5 < p_T^{assoc} < p_T^{trig1}$. Errors shown are statistical. c) p_T spectra per trigger pair for the same-/away-side associated hadrons ($|\Delta\phi| < 0.5$, $|\Delta\eta| < 0.5$). Errors are the quadrature sum of the statistical and systematic uncertainties. Inclusive charged hadron spectra from 10% most central Au+Au data [13] is shown for comparison.

The symmetric trigger work shown in Fig. 1 is from most recent STAR 2+1 correlation publication [10]. The $\Delta\phi$ and $\Delta\eta$ projections (symmetrized about 0) of the correlation function are plotted in Fig. 1a and b respectively. This measurement constitutes the first observation of not only the near-side, but also the away-side correlation structure in central Au+Au reproducing those of d+Au as a reference (without hot quark matter), in both $\Delta\phi$ and $\Delta\eta$, for the associated hadrons in this kinematic range. No evidence of dip or ridge is present. However, statistical limitations prevents a complete exclusion of ridge [3]. The similarity between Au+Au and d+Au is further supported by their associated hadron p_T spectra plotted in Fig. 1c, on contrary to previous di-hadron correlations measurements in a similar kinematic range, where significant softening of the away-side spectra is observed [1] indicating energy deposition in the medium. The jet energy is then estimated by summing the p_T of trigger and charged associates spectra. The result in the 12% central Au+Au data $\Delta(Au + Au) = \Sigma(p_T)^{same} - \Sigma(p_T)^{away} = 1.59 \pm 0.19 \text{ GeV}/c$, similar to the minimum bias d+Au data value of $\Delta(d + Au) =$

1.65 ± 0.39 GeV/c. This number is close to the initial state kinematic effects 1.6 GeV/c [12] and disfavors additional partons losing energy into medium in Au+Au case.

As a conclusion, the 2 + 1 results are consistent with lack of medium-induced effects on those di-jets selected by this analysis, and favors a surface jet emission model. This model is then tested by measuring the nuclear modification factors R_{d+Au}^{Au+Au} (ratio of binary-scaled per-event trigger counts in Au+Au and d+Au data) for the primary (single) triggers and di-jet triggers as shown in Fig. 2a.

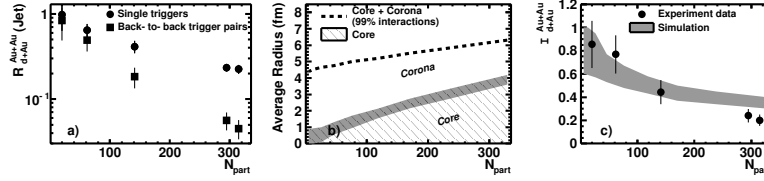


FIGURE 2. Comparison between data and model [10]. *a*) Relative production rates for jets and di-jets in Au+Au of different centralities with respect to d+Au. *b*) Calculations of the Glauber-based core/corona model that accommodates inclusive hadron suppression and single jet production rate results. *c*) Conditional di-jet survival probability in Au+Au data compared to d+Au reference. The points are from data. The shadow band shows the expectations from Glauber-based core/corona model described in the text. Error bars in *a*) and *c*) are the quadrature sum of the statistical and systematic uncertainties.

A Monte Carlo Glauber model based on surface emission is applied, assuming the medium in heavy-ion collisions consists of a completely opaque core (full jet absorption) surrounded by a permeable corona (no jet-medium interactions). The relative size of the core is estimated from the R_{AA} of single triggers [14, 13] because they are purely from the corona and bypass the core in this model. The calculation is shown in Fig. 2b. The model then calculates the conditional survival probability of di-jets $I_{d+Au}^{Au+Au} = \frac{R_{AA}(trigger-pairs)}{R_{AA}(single-triggers)}$ and compares with the experimental data, shown in Fig. 2c. The data are symbol points, and the expected rates from core/corona model are shown as a band, where the width reflects the uncertainty in the published R_{AA} data. They agree with each other qualitatively. However, core emission where neither of the di-jets interacted with the medium cannot be ruled out by this analysis.

As for the path-length dependent energy-loss models where in-medium energy loss followed by in-vacuum fragmentation, trigger pairs of similar p_T can possibly bias towards partons travel similar path length of medium and lose similar energy. Thus highly asymmetric trigger pairs in p_T are selected as proxy of di-jets of big asymmetry in energy loss. The primary triggers are BEMC tower clusters of $10 < E_T^{trig1} < 15$ GeV dominated by decayed π^0 s. The direct- γ s contamination is non negligible [15] but won't affect the validity of comparison, as direct- γ s don't lose energy in the medium and away-side parton will lose relatively more energy if path-length dependence stands.

The correlations are shown in Fig. 3 *a* and *b*. Similar jet-like peak shapes and magnitudes sustain from d+Au to central Au+Au collisions at both same-/away-sides. Again, no evident ridge or dip structure is observed in Au+Au data. The away-side magnitude is higher than near-side in both Au+Au and d+Au, which can be due to either the direct- γ contamination in primary trigger, or momentum conservation at lower- p_T trigger (away-)side if back-to-back jets are of similar energy. On the other hand, such difference varies little from d+Au to Au+Au, indicating no evidence of asymmetry in energy loss of sur-

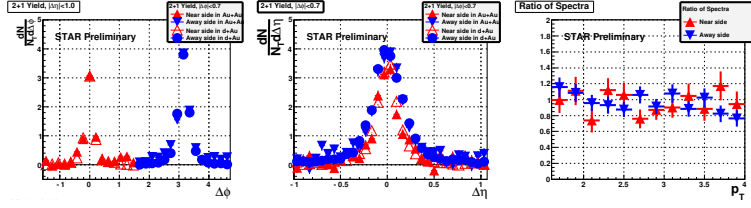


FIGURE 3. 2+1 correlation in asymmetric trigger case. Projections of 2+1 correlation for 200 GeV Au+Au and d+Au data on a) $\Delta\phi$ and b) $\Delta\eta$: $10 < E_T^{trig1} < 10$ GeV, $4 \text{ GeV}/c < p_T^{trig2} < 10 \text{ GeV}/c$, $1.5 < p_T^{assoc} < 10 \text{ GeV}/c$. c) Au+Au spectra divided by d+Au. Errors shown are statistical.

living parton pairs expected from path-length dependence model [12]. The ratios of Au+Au associates spectra at either trigger side divided by d+Au are plotted in Fig. 3c. These ratios are consistent with flat and close to unity at either trigger side, showing no evidence of softening or strong suppression, and further supports the assumption of strong surface-bias whenever a jet-like structure is observed.

SUMMARY

The mechanisms of jet-medium interactions was investigated using a novel technique called 2 + 1 correlations, studying low- p_T hadrons associated with a correlated pair of back-to-back high p_T particles as proxy of di-jets. Both same-/away-side correlations are found similar from d+Au to central Au+Au data, and so is the associated hadron spectra on each trigger side, in the kinematic range selected of $p_T^{assoc} > 1.5 \text{ GeV}/c$. The path-length dependence energy loss models expect that in either symmetric or very asymmetric trigger pairs cases such similarity shall be broken for di-jets if they are from deep within the medium (non-tangential), which wasn't observed at this stage of analysis within the errors. Meanwhile, systematic assessment of di-jet production rates supports tangential emission bias in a simplistic core/corona scenario.

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